

# **Northern bog lemmings: survey, population parameters, and population analysis**

**A Report to:  
USDA Forest Service**

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**April 1997**

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This document should be cited as follows:

Reichel, J. D. and J. G. Corn. 1997. Northern bog lemmings: survey, population parameters, and population analysis. Unpublished report to the Kootenai National Forest. Montana Natural Heritage Program. Helena, MT. 27 pp.

## ABSTRACT

Northern bog lemmings (*Synaptomys borealis*) were discovered in 1992-3 in single patches within the Cody Creek and South Fork Hawkins Creek drainages. During the 1994 field season we surveyed these two drainages to determine the number, size and location of other suitable habitat patches. No suitable habitat patches larger than about 50 m<sup>2</sup> were located. The total number of known bog lemming sites in Montana is 18, the most sites in any of the lower 48 states. Known sites in Montana range in size from 1 to approximately 340 acres. The best habitat predictor for potential northern bog lemmings sites in Montana is the presence of large, thick moss mats, particularly sphagnum moss.

## ACKNOWLEDGMENTS

We would like to thank Bob Summerfield and Seth Diamond for their help throughout the study. D. E. Pearson provided access to his invaluable unpublished information. S. W. Chadde, S.V. Cooper, J. C. Elliott, and B. L. Heidel identified plants and plant communities. Help with field work and other logistical support was provided by G. Altman, J. Berry, A. Bratkovich, and other Forest Service personnel. M. Beer, D. Dover, C. Jones, and K. Jurist helped with database applications and mapping in the preparation of the report. L. S. Mills and J. Caratti provided helpful criticism of earlier versions of a PVA model. Financial support for the project came from the Kootenai National Forest (U.S. Forest Service) and the Montana Natural Heritage Program (Montana State Library).

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## INTRODUCTION

The northern bog lemming (*Synaptomys borealis*), a small, grayish brown, vole-like microtine, is related to the true arctic lemmings (*Lemmus*). Nine poorly differentiated subspecies are currently recognized (Hall 1981). The northern bog lemming has a total length of 118-140 mm including its very short tail (19-27 mm) (Banfield 1974, Hall 1981). The combination of a tail less than 28 mm long and a longitudinal groove in the upper incisors distinguish the northern bog lemming from all other mice found in Montana.

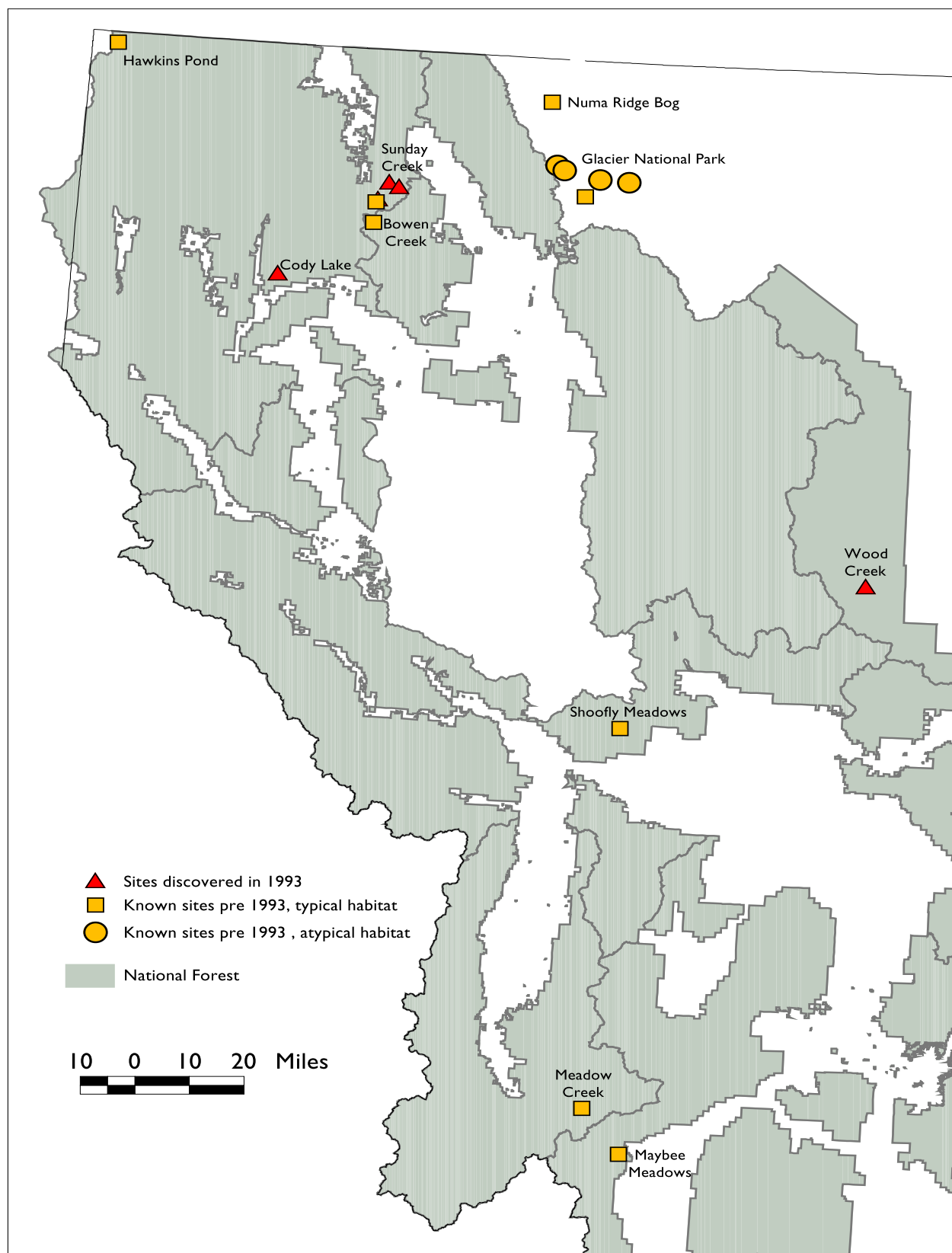
The northern bog lemming is boreal in distribution, occurring in North America from near treeline in the north, south to Washington, Idaho, Montana, Minnesota, and New England. It typically inhabits sphagnum bogs and fens, but is also occasionally found in other habitats including mossy forests, wet sub-alpine meadows, and alpine tundra. One subspecies (*S.b. artemisiae*) lives on sagebrush hillsides in eastern British Columbia (Anderson 1932). The northern bog lemming is rarely trapped and is one of the least known mice in North America. It is listed as a Species of Special Concern by the Idaho, Minnesota, Montana, and New Hampshire Natural Heritage Programs, and on the Special Animal Priority List of the Washington Natural Heritage Program. The subspecies *Synaptomys borealis artemisiae* is listed as a Species of Special Concern by the British Columbia Conservation Data Centre.

A few relict populations occur in the lower 48 states; the subspecies *chapmani* occurs in Montana, Idaho, and northeast Washington (Hall 1981). Bog lemmings are known from 4 locations in Idaho and 8 in Washington, all from within 80 km of the Canadian border (Johnson and Cheney 1953, Wilson et al. 1980, Reichel 1984, Groves and Yensen 1989, D. Johnson pers. comm.). Prior to 1992, evidence of bog lemmings in Montana included: 1) 6 locations on the west side of Glacier National Park (Wright 1950, Weckwerth and Hawley 1962, Hoffmann et al. 1969, Pearson 1991); 2) Shoofly Meadows in the Rattlesnake drainage north of Missoula (Adelman 1979), and 3) a single skull recovered from a Boreal Owl (*Aegolius funereus*) pellet west of Wisdom (J. Jones pers. comm.); where the owl captured the lemming was unknown. In 1992 and 1993, 51 sites were trapped which located 10 new populations of northern bog lemmings (Figure 1) (Reichel and Beckstrom 1993, 1994). The Maybee Meadows site is the southern-most known population of the species outside of New England and one of two Montana populations known from east of the Continental Divide. All 10 sites found in 1992-1993 were associated with thick mats of moss. Their disjunct distribution and rarity may be due to: 1) the localized nature of their primary habitat; and 2) their currently patchy distribution from more widely distributed populations during the Pleistocene (a glacial relict).

Species like the northern bog lemming—rare, patchily distributed, confined to rare habitats—are at particular risk of extinction (Shaffer 1981). Population viability analysis (PVA) is one means of assessing a population's risk of extinction quantitatively. PVA models that incorporate demographic and environmental stochasticity (uncertainty) in population trend are particularly powerful analytical tools, and are available in user-friendly computer programs. Stochastic PVAs require extensive background information on the population's demographic characteristics (fecundity and survival rates).

Unfortunately, little is known about northern bog lemming life history and demography. A few notes in the literature indicate litter sizes vary from 3-8, with 2 (or possibly more) litters

Figure 1. Northern Bog Lemming occurrences in Montana. Locations are from Wright (1950), Weckwerth and Hawley (1962), Adelman (1979), Pearson (1991), Reichel and Beckstrom (1993), and this report.



per year. It has been suggested that some individuals breed the same year they are born (perhaps 60-90 days old). Most reproduction information is scattered throughout a literature that deals mainly with distribution.

More is known about the northern bog lemming's congener, the southern bog lemming (*S. cooperi*). Southern bog lemmings are distributed in eastern and central North America, from southeastern Canada west to Minnesota, and south as far as Kansas and North Carolina. They inhabit a wide variety of habitats, but, like northern bog lemmings, tend to be associated with sphagnum bogs in eastern forests (Linzey 1983). Population densities also vary widely, from 4 - 51/ha (Linzey 1983). Detailed population studies conducted for southern bog lemmings in Kansas (Gaines et al. 1977, 1979), Illinois (Beasley and Getz 1986), and Virginia (Linzey 1983) indicate that breeding occurs all year in the southern part of its range, but ceases in winter in the northern part of its range. We used these data to estimate population densities and demographic parameters in a PVA for the northern bog lemming. The lack of species-specific data makes the model necessarily preliminary, but nonetheless it can be used to suggest what additional biological information is essential to develop a sound bog lemming management plan.

A multi-year study of northern bog lemmings in Montana was begun in 1992. Objectives during 1994 included:

- 1) Determine the extent of the suitable habitat in the Cody Creek and Hawkins Creek drainages.
- 2) Review the available information on northern bog lemmings and closely related voles to develop a model of population viability; we will discuss which parameters are weakest and what additional data are necessary to strengthen our confidence in the model.
- 3) Determine what additional biological information is most critical for development of a bog lemming management plan.

This report also contains a summary of habitat characteristics at bog lemming capture locations in Montana.

## **METHODS AND MATERIALS**

### Surveys

We visited Cody Creek and Hawkins Creek drainages in western Montana, examining riparian habitats to determine their suitability for northern bog lemmings. We walked much of both drainages within three miles of the known bog lemming areas, and used aerial photos and USGS 7 ½ -minute topographic maps to find locations of potential bog lemming habitat. All areas within the drainages which looked potentially suitable were examined.

### PVA Model Development

We evaluated documentation for several of the PVA computer programs most widely available for use on a PC, and chose RAMAS/GIS (Applied Biomathematics, Setauket, NY) for the analysis. This program uses an age- or stage-based population growth matrix, includes stochastic variation in population change, and accommodates metapopulation dynamics, with movement of individuals between habitat patches, or populations (Akçakaya 1993).

Appendix I defines parameters in the population growth matrix. To estimate values for the matrix parameters, we used information from northern bog lemming museum records, and data from demographic studies of southern bog lemmings. We obtained museum data by contacting all museums with medium to large mammal collections in the U.S. and Canada. They were asked to provide data on

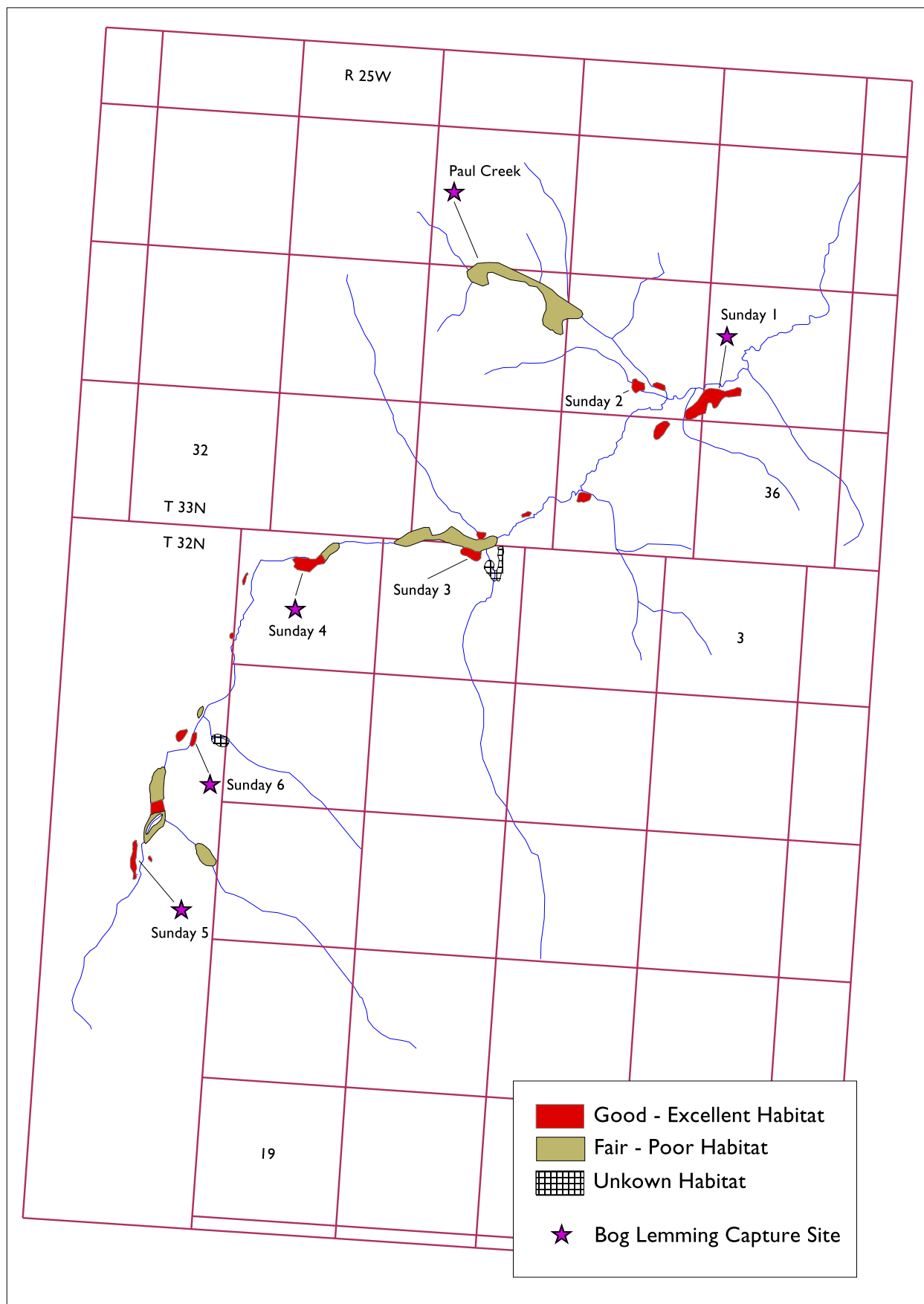
all northern bog lemmings in their collections including catalog number, date, sex, weight, location, and collector. Additionally they were asked to provide any data on specimens which had reproductive information associated with them; for females: embryos, placental scars, perforate/imperforate vagina, lactation; for males: testis or seminal vesicle size, scrotal/inguinal testes. We estimated the timing and duration of the breeding season, and the proportion of females breeding by summarizing museum data to determine the total number of females collected per month, and the number and percentage of pregnant females each month. For each breeding interval, we estimated litter size from embryo counts, with separate estimates for subadults and adults. Age class was determined from museum records, or was based on body mass, a reliable indicator of age in the southern bog lemming (Gaines et al. 1997). We estimated survival rates of subadults and adults from demographic studies of southern bog lemmings (Beasley and Getz 1986, Gaines et al. 1977). We used these parameter estimates in a stage-structured population projection with 3 stages (subadults, adults breeding for the first time, and adults breeding for the second time), with a pre-birth pulse and 2 litters per year (Appendix I). The projection interval (i.e. the time step for calculating survival) is 3 months, the average interbirth interval.

We chose the complex of 25 habitat patches on Sunday Creek, of known or potential use by northern bog lemmings, as the basis for the PVA (Figure 2), with each  $\delta$ patch =  $\delta$  defined as a population, and the entire complex in the Sunday Creek drainage defined as the metapopulation. For the preliminary metapopulation analysis reported here, we assumed that all patches were of equal habitat quality (i.e. population density did not vary between patches), with population sizes varying only according to patch size. Thus, even though the small bog habitats ( $\delta$ good-excellent habitat =  $\delta$  patches in Figure 2) are thought to be the primary habitat for northern bog lemmings, their importance relative to lower quality, but typically larger, habitat patches is not quantified in the PVA, because data for that type of simulation are not available. The implications of the assumption of equal habitat quality will be discussed in later sections of this report.

The initial population size of each population of bog lemmings in Sunday Creek was determined by the areal extent of each habitat patch (from MNHP records) and density estimates for southern bog lemmings. We estimated initial population density as 12 lemmings/ha, the density of southern bog lemmings at the margin of their range in forested habitats of northeastern US, comparable conditions to northern bog lemmings in MT. The initial population stage structure was assumed to be a stable age distribution, and was calculated by the program. We simulated population growth as an exponential growth function to a ceiling (K, carrying capacity; Appendix I). K was calculated from the maximum densities reported for southern bog lemmings (51/ha; Gaines et al. 1977, 1979).

Stochastic variation in population growth rate was estimated using the standard errors of estimates of average litter size, proportion of females breeding, and survival obtained from museum records or the literature. We assumed that environmental stochasticity is completely correlated across populations, because the Sunday Creek drainage is an area of limited extent likely experiencing similar environmental conditions across populations.

Figure 2. Sunday Creek bog lemming complex showing potential and known habitat patches.



Movements of animals between populations were assumed to be constant across age classes at 0.10. Dispersal rates were distance-dependent, as defined by a distance function in the RAMAS/GIS program (Akçakaya, 1993). Distances between populations were calculated from the center of each population by the program, using UTM coordinates of each population. The program calculates dispersal of survivors, so each estimate of survival rate was increased by the dispersal rate to allow for dispersal loss from populations. We assumed all age classes were equally likely to disperse, and initially set the average dispersal distance at 100 m and the maximum dispersal distance at 500 m.

#### PVA Model Output

Simulations were initially run for short intervals (10 years with 50 replicates) to determine whether population parameters were reasonable; the long-term projection was 50 years with 1000 replicates per simulation. RAMAS/GIS reports a variety of simulation results (Akçakaya 1993); we report (1) final metapopulation occupancy (average [S.D.] number of extant populations [occupied patches]; (2) quasi-extinction risk (probability [95 % CI] that the metapopulation will fall below 100 individuals at the end of the simulation) (3) time to quasi-extinction (median time of quasi-extinction, distribution of extinction times, and cumulative extinction probability).

#### PVA Model Modifications

The basic simulation described above was modified to test the effects of dispersal distance and life-history variables on the outcome of the PVA. Average dispersal distance was increased from 100 m to 500 m, and maximum dispersal distance from 500 m to 5 km. Additionally, the original values for adult fecundity or survival probability were increased by 0.10 and subsequently decreased by 0.10 and PVA outcomes compared to test the effects of their variation on PVA outcomes life-history variables most sensitive to change. Differences between simulations in quasi-extinction risk were tested using the Kolmogorov-Smirnov test statistic (Akçakaya 1993).

## **RESULTS**

#### Surveys

One of us (J. Reichel) visited the Hawkins Creek drainage on 11 September 1994, and the Cody Lakes area 8 September 1994. Both areas appeared to be of low potential for northern bog lemming habitat. No suitable habitat patches larger than about 50 m<sup>2</sup> were located. This extent is substantially smaller than the smallest habitat patches used by bog lemmings in Montana (1 ac. or approximately 4,046 m<sup>2</sup>). The sites examined were not trapped in 1994, however.

#### PVA Model

We contacted 39 museums for information pertaining to northern bog lemmings in their collections (Appendix II). Twenty-three museums sent us data on a total of 484 animals from 16 provinces and states. Specimens from Alaska (139) and Manitoba (94) dominated the collection; specimens from Alberta (42), British Columbia (37), Quebec (64), and the Yukon (47) were also well

represented in collections. The remaining 10 states and provinces were the source of fewer than 20 lemmings each, 8 of those states or provinces were the source of fewer than 10 specimens.

The distribution of reproductive activity from museum specimens suggests a 6 month breeding season with 2 litters per year, April - June, and July - September (Table 1). The earliest date any museum specimen was captured which had embryos was 27 April and the latest date was 1 October. However, one female weighed only 11.8 g on 31 March, which indicates that at least some breeding takes place over the winter.

In the museum specimen sample, breeding prevalence was lower and litter sizes were smaller on average for subadults than adults, and litter sizes for adults was smaller for the second litter than the first litter of the year. For subadults, the proportion of females breeding in the first litter of the year was 0.57 (4 of 7), and litter size averaged 3.5 (SE = 0.5, N = 4); in the second litter of the year, the proportion of females breeding was 0.125 (5 of 40), and litter size averaged 3.25 (SE = 0.829, N = 5). For adults, the proportion of females breeding in the first litter of the year was 0.75 (18 of 24), and litter size averaged 4.28 (SE = 1.63, N = 18); in the second litter, proportion of females breeding was 0.4848 (32 of 66), and litter size averaged 3.9 (SE = 1.1, N = 32).

Beasley and Getz (1986) found that individual survival probability from birth to adult age in the southern bog lemming was 0.0681 (SE = 0.0575). Correcting the survival rate for dispersal (increasing the estimated survival rate by 0.1) increased the survival rate to adult age to 0.1681. We assumed that survival from birth to adult is constant over the interval birth to subadult and subadult to adult, and estimated the rates of survival of each of these two intervals as  $(0.1681)^{1/2}$ , or 0.4100.

Southern bog lemmings have an average adult 2-week survival rate of 0.7067 (SE = 0.499) in summer, and 0.7683 (SE = 0.0601) in winter (Gaines et al. 1977). Survival over the prediction interval (3 months), is the 2-week survival rate multiplied 6 times, or  $0.7067^6$  (=0.1245) in summer, and  $0.7683^6$  (=0.2057) in winter. Dispersing adults were taken into account by adding 0.1 to summer and winter adult survival rates, increasing them to 0.2245 and 0.3057, respectively. These estimates of life history parameters were used to calculate variables used in the Leslie matrix (see Appendix I for details). The resulting Leslie matrix is:

0.492	1.3161	0.7752
0.4100	0.3166	0

Demographic and environmental stochasticity was modeled from the standard errors of the estimates for survival, litter size, and proportion of females breeding used in the population matrix (see Appendix II). The Leslie matrix for stochasticity is:

0.1659	0.3910	0.2639
0.2399	0.0419	0

Table 1. Timing of reproduction in northern bog lemmings, as estimated from museum specimens.

Month	number of female specimens	number with embryos noted	percent with embryos
January	0	0	0
February	0	0	0
March	0	0	0
April	2	1	50
May	12	9	75
June	25	12	48
July	38	15	39
August	72	17	24
September	26	3	11
October	3	1	33
November	0	0	0
December	0	0	0
Total	178	58	33

### PVA Model Output

The stable age distribution for northern bog lemmings, calculated by RAMAS/GIS from the Leslie matrix, was dominated by subadults (66 %), compared to 34 % older adults breeding for the first or second time. A preponderance of subadults in the trappable population is observed in small mammals during the breeding season (pers. obs.), suggesting that the Leslie matrix is a reasonable estimate for this species. The finite rate of population increase ( $\lambda$  [lambda]) predicted by this Leslie matrix is 1.0755, which indicates an increasing population ( $\lambda > 1$ ). However, when stochasticity is introduced into the population projection, population growth may not occur.

From the basic model, with average and maximum dispersal distances of 100 m and 500 m, respectively, only 5.4 populations (N=1000 replications) remain occupied after 50 years. The probability of quasi-extinction (<100 individuals) in the metapopulation is 0.257 at 50 years, and the median time to quasi-extinction is 26.2 years (Figure 3, Table 2).

### PVA model modifications

Table 2 summarizes the outcome of the population projection for the Sunday Creek metapopulation under the various modeling scenarios. By increasing average distance moved from 100 m to 500 m, and maximum distance from 500 m to 5 km, probability of quasi-extinction increased and median time to quasi-extinction decreased over 50 years relative to the simulation with shorter dispersal distances (Table 2). However, the average number of occupied patches after 50 years was higher with increased dispersal distance (9.2).

The results of manipulation of fecundity and survival rates indicates that the model is sensitive to both variation in fecundity and survival rates, but variation in fecundity rates may affect population projection more than to those of survival rates (Table 2). When adult fecundity rates were decreased by 0.10, the probability of quasi-extinction more than doubled, and median time to quasi-extinction decreased by almost 1/2 half (Table 2); when fecundity was increased, quasi-extinction probability decreased accordingly. In contrast, increasing or decreasing adult survival rates by 0.10 had less pronounced, but still highly significant, effects on quasi-extinction risk. All simulations resulted in relatively high quasi-extinction probability (Akçakaya 1993).

Figure 3. Distribution of probability to quasi-extinction (<100 individuals) over 50 years (100 simulations) in the Sunday Creek metapopulation of northern bog lemmings. Vertical bars indicate probability of quasi-extinction during a given year; continuous solid line is cumulative quasi-extinction probability; continuous dashed lines are 95% confidence intervals.

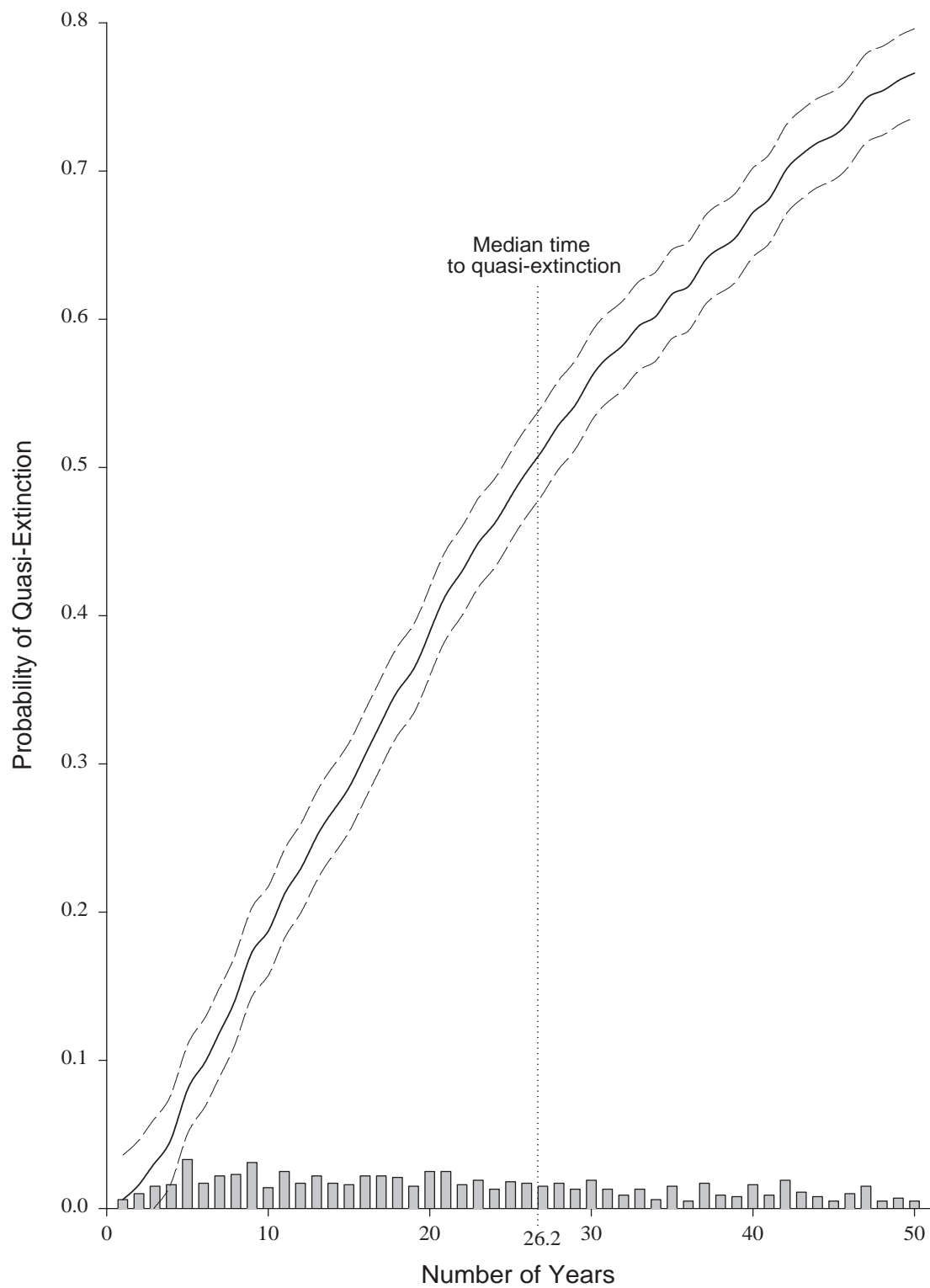


Table 2. PVA results for the northern bog lemming on Sunday Creek. The basic simulation modeled the population projection with average and maximum dispersal distances of 100 m and 500 m, respectively. The details of the remaining modifications to the model are described in the text. Difference test results are Kolmogorov-Smirnov test statistic  $D$  and significance level (\*=0.05, \*\*=0.01, \*\*\*=0.001) for difference between the basic model and each model modification.

Simulation	Average number (s.d.) of extant populations after 50 years	Median time (years) to quasi-extinction	Extinction probability after 50 years	Difference test	
				$D$	signif.
Basic	5.4 ( 6.3)	26.2	0.257	-	-
Increase dispersal distance	9.2 (9.8)	22.1	0.331	0.08	**
Increase fecundity 10%	8.6 ( 7 )	36.2	0.158	0.19	***
Decrease fecundity 10%	2.6 (4.6 )	16.6	0.572	0.33	***
Increase survival rate 10%	7.1 (7.2)	28.2	0.258	0.1	***
Decrease survival rate 10%	3.7	19.5	0.459	0.2	***

## DISCUSSION

### Distribution.

While northern bog lemmings were not found in the surveyed areas, it is within their range in Montana which includes the northwest corner of the state east to the Rocky Mountain Front, south through the mountains to Lost Trail Pass on the Continental Divide (Figure 1). The Maybee Meadows site is the southern-most site known for the species outside of New England; two sites in New Hampshire are about 160 km farther south (Clough and Albright 1987; Reichel and Beckstrom 1993, 1994). The Maybee Meadows and Wood Creek sites are the only known northern bog lemming sites east of the Continental Divide in Montana. We expect additional populations will be found across western Montana, perhaps as far south as Yellowstone National Park, and possibly east to mountain ranges such as the Little Belt Mountains. The known elevation range for Montana is from 1018 m (3340 ft.) (McDonald Creek, Pearson 1991) up to 1987 m (6520 ft.) (Maybee Meadows, Reichel and Beckstrom 1993).

### Detectability.

During 1992-1993 lemmings were found at 10 of 17 sites that appeared to have suitable lemming habitat. Either lemmings were at 7 of those sites and we failed to detect them, or we sampled 7 sites with apparently good habitat which lacked lemmings. A combination of the two is a possibility (Reichel and Beckstrom 1993, 1994). The percentage of sites with good habitat which had lemming captures was slightly higher than that of Pearson (1991) who found lemmings at 3 of 11 bog/fen sites trapped with Sherman live traps in 1989-90.

### Habitat Patches.

Bog lemmings have been found in at least nine community types (Table 3). However, peatland communities constitute a very small proportion of the landscape in Montana and have not been adequately classified (Bursik and Moseley 1992). Whether new information on these fens will result in newly defined community types which closely approximate habitat used by northern bog lemmings remains to be seen. Extensive thick moss mats were present in all but one of the lemming sites found during our previous surveys (Reichel and Beckstrom 1993, 1994), and were also present at Numa Ridge Bog, McGee Meadows (Pearson 1991, P. Lesica pers. comm.) and Shoofly Meadows (Pearson 1991, S. Chadde pers. comm.).

In 1993 J. Reichel spent several hours along Camas Creek in the vicinity of the first lemming population known from the state (Wright 1950) and found only scattered clumps of moss. Weckwerth and Hawley (1962) did not adequately describe the two specific sites where they captured bog lemmings, but they were visited by D. E. Pearson (pers. comm.) who found that they were not located in fens or covered by thick moss mats. At these three sites trapping was conducted multiple years, often twice each year (Camas Creek: 18 years [Hoffmann et al. 1969]; Anaconda #1: 6 years spring and fall [Jonkel 1959]; Anaconda #6: 4 years spring and fall [Jonkel 1959]). Despite this intensive trapping, only 3 individuals have been taken in Camas Creek in 2 of 18 years, and 1 individual at each of the two Anaconda Creek sites. A similar situation exists with the McDonald

Table 3. Plant communities present at 6 northern bog lemming sites.

<b><u>Community\phase</u></b>	<b><u>Sunday Creek</u></b>	<b><u>Cody Lakes</u></b>	<b><u>Bowen Creek</u></b>	<b><u>Wood Creek</u></b>	<b><u>Maybe Meadows</u></b>	<b><u>Meadow Creek</u></b>
Abies lasiocarpa \\Calamagrotis canadensis	yes					
Picea \\Salix geyeriana- Carex utriculata				yes		
Salix drummondiana	yes					
Salix planifolia- Salix wolfii \\Carex aquatilis					yes	
Betula glandulosa \\Carex utriculata					yes	
Betula glandulosa- Eleocharis pauciflora \\Carex lasiocarpa		yes				
Betula glandulosa- Carex lasiocarpa			yes			
Carex utriculata (=C. rostrata)					yes	yes
Eleocharis pauciflora		yes				

Table 4. Characteristics of known bog lemming sites, plus several additional sites in the Sunday Creek complex, in Montana.

Site	Location	Elevation (meters)	Distance to nearest site		Potential (km)
			Size <sup>1</sup> (ha)	Known (km)	
Hawkins Pond	T37N R33W S18	1890	2	60 <sup>2</sup>	?
Numa Ridge Bog	T36N R20W S21	1536	0.8-1.6	23	5
Anaconda Creek West	T34N R20W S27	1097	? <sup>3</sup>	2.8	<6.9
Anaconda Creek East	T34N R20W S36	1097	? <sup>3</sup>	2.8	<6.9
Camas Creek	T33N R19W S12	1158	? <sup>3</sup>	11	<6.5
McGee Meadows	T33N R19W S27	1180	137.6	6.5	<3.2
McDonald Creek	T33N R18W S12	1043	? <sup>3</sup>	8.9	4
Sunday Creek complex	T32-33N R25-26W	1286-1463	85	6.6	6.4
Site 1	T33N R25W S25	1286	9	1	0.2
Site 5	T32N R26W S13	1463	12.1	0.3	0.3
Site 6	T32N R26W S12	1426	2	0.3	0.3
Paul Creek	T33N R25W S27	1353	24.7	1.7	1
*Site 2	T33N R25W S26	1289	2.4	0.5	0.5
*Site 3	T32N R25W S5	1311	18.2	2.6	0.6
*Site 4	T32N R25W S6	1359	6.5	2.3	0.5
Bowen Creek	T31N R26W S1	1451	9.3	6.6	0.2
lower Cody Lake	T29N R28W S6	1433	2.4	32	?
Wood Creek	T20N R10W S26	1704	0.8	90	<13
Shoofly Meadows	T14N R17W S4	1792	9.7	90	<14
Meadow Creek	T01N R18W S10	1804	0.4	19	<18
Maybee Meadows	T01S R17W S26	1987	3.2	19	1.8

\* Sites in Sunday Creek complex with suitable habitat, but no bog lemmings trapped in 115-215 trap-nights per site

<sup>1</sup> Size of habitat patch, or patches with less than 100 m separation between patches

<sup>2</sup> nearest site at Cow Creek, Idaho

<sup>3</sup> site lacks typical bog lemming habitat with deep moss; see text.

Creek site which is in old-growth western hemlock (*Tsuga heterophylla*) forest (Pearson 1991); this site has been trapped multiple times yielding only a single lemming (June 1991 - September 1993, total 3600 trap-nights, D. E. Pearson, pers. comm.). Apparent high quality habitat patches exist within 7 km of all four sites (Table 9, 10 in Pearson 1991; P. Lesica, pers. comm.). It seems likely that these sites are very marginal and/or that the individuals were found while dispersing from a nearby high quality site.

Some habitat descriptions of *S. b. chapmani* trapping sites in the northern Rocky Mountains have sometimes included mention of sphagnum moss (Layser and Burke 1973, Groves and Yensen 1989) while others have not (Wilson et al. 1980). J. Reichel captured a single juvenile male lemming on a dry alpine/subalpine ridge in northeast Washington (Wilson et al. 1980).

Areas with extensive moss mats, particularly sphagnum, are the most likely sites in which to find new bog lemming populations in Montana. Other habitats in Montana may either support lower densities of bog lemmings; be used primarily by dispersing individuals; be used during specific seasonal, climatic, or competitive situations; or be population sinks. Marginal habitats and areas may be important to maintain population viability. The only certainty is that there is much to be learned about habitat use by northern bog lemmings.

Patch size of known bog lemming sites in Montana varies from 0.4-137.6 ha, with 7 of 13 being less than 4 ha (Table 4). No patch sizes are known for 4 sites since they are not in typical habitat (see preceding paragraph). Most sites found thus far in Montana appear to be patches within potentially larger metapopulation patch complexes. These could include: a Sunday Creek complex with a Bowen Creek complex; a Maybee Meadows complex possibly with the Meadow Creek patch; and a McGee Meadows complex which may be part of a larger complex in Glacier National Park. However, several small patches appear to be isolated. Numa Ridge Bog (0.8-1.6 ha) is 5 km from the nearest fen/bog patch (Pearson 1991). Shoofly Meadows is larger (9.7 ha) but may be 14 km from another suitable patch. Wood Creek is certainly at the extreme, having only about 0.8 ha of moss mat habitat and being 13 km from the nearest known potential site. While there appear to be substantial amounts of marginal habitat along Wood Creek which might support bog lemmings, much of the riparian habitat has been heavily impacted by domestic livestock grazing.

#### PVA model.

The PVA model has helped us identify several aspects of northern bog lemming population biology that are central to population persistence, and yet remain poorly known for this species. First, we developed a PVA model without species specific life history data, a highly speculative exercise (Akçakaya 1993). Although we had some fecundity data on northern bog lemmings (from museum specimens), we used demographic data from the southern bog lemming to estimate survival rates, because no comparable data are available for the northern bog lemming. Unfortunately, the sensitivity analysis showed that survival rate has as great an effect on the PVA projections as fecundity rate. Data on survival rate for northern bog lemmings is critical if the model is to have any validity. Without it, a PVA model such as the one developed here lacks sufficient validity to be used as a management tool.

Secondly, our PVA simulations suggest that movement is very important for the persistence of northern bog lemmings in complexes of small habitat patches. When average and maximum movement distances were increased, the number of habitat patches where lemmings persisted almost doubled, although extinction rate increased as well. Long movements may occur, but their frequency is not known.

Finally, the preliminary modeling effort reported here did not attempt to quantify habitat quality using the Landscape Data subprogram in RAMAS/GIS, because effects of different habitat types on density have not been quantified for the northern bog lemming. Our sense is, and the literature generally supports the notion, that bogs support more bog lemmings than other habitats. The effects of different habitat types on northern bog lemming densities is not known, but is central to the management of this species.

The importance of representing habitat quality in PVA analysis is demonstrated by some counterintuitive results in our simulation of a catastrophic event, the removal of the central population 'Sunday 4' (Figure 2). Removing Sunday 4 from the metapopulation analysis did not increase the likelihood of extinction, as we would expect based on the quality of the habitat. Rather, probability of extinction declined by 0.10. Population density of Sunday 4 (actually 2 small patches) is low, because population size in the simulation was based only on areal extent of patches. Sunday 4 was prone to local extinction in almost every simulation. When the metapopulation does not include this population, chance of quasi-extinction appears to be reduced accordingly. We know, however, that the presumed high quality habitat of Sunday 4 and its central location in this linearly arranged chain of patches, makes this patch of central importance to bog lemming metapopulation on Sunday Creek. The relative importance of different habitat types should be examined for this species in order to quantify habitat quality for incorporation into a PVA using the Landscape Data subprogram in RAMAS/GIS. The program RAMAS/GIS could be a powerful tool for examining how different patches in a complex such as Sunday Creek affect metapopulation process if density could reflect habitat quality.

This leads to questions about what constitutes a viable population of northern bog lemmings. Three (somewhat) alternative hypotheses could apply: 1) lemmings live in habitat patches which have been isolated for thousands of years; 2) lemmings move substantial distances between patches supplementing (or recolonizing) the sub-population within a patch and contributing genetic material; and 3) lemmings use habitats other than moss bogs/fens.

Alternative 1. Populations within patches such as Wood Lake and Numa Ridge Bog would not appear to have been able to survive given the small habitat patch size, if they are indeed totally isolated and if lemmings do not use habitats other than moss mats. This leads us to think that this alternative is not completely feasible.

Alternative 2. In several areas such as the Sunday Creek complex, the distribution and size of known patches suggests movement between patches. The overall view that most patches in Montana are relatively near other known, or potential, patches, gives support to this hypothesis. Arctic lemmings are known to make spectacular movements during highs in the population cycle; this could also be true of northern bog lemmings. Northern bog lemmings do undergo population fluctuations at least in central Canada (Edwards 1963). However, population cycles in general appear to be less dramatic in: 1) more southerly areas, and 2) in areas with less contiguous habitat for the cycling species.

Alternative 3. Lemmings have certainly been found in habitats other than bogs/fens in Montana and in other areas of their range. In the Montana sites where the habitat is atypical, captures represent a rare

event. Multiple trapping periods prior to and/or following a capture have not resulted in regular additional captures of lemmings. In Glacier National Park, general trapping for small mammals over nearly 100 years in numerous habitats has resulted in captures of 5 lemmings at 4 sites (all atypical habitats) (Wright 1950, Hoffmann et al. 1969, Weckwerth and Hawley 1962, Pearson 1991). In the rest of Montana, only 1 site has been found during general small mammal trapping (Shoofly Meadows, a typical habitat site) (Adelman 1979). However, when trapping focused on bog/fen habitat, 12 new sites were discovered since 1990 (Pearson 1991, Reichel and Beckstrom 1993, 1994). Many of these sites have had multiple animals captured in a single night, supporting the premise that the fen/bog habitat is the primary habitat for northern bog lemmings in Montana. The extent of lemming use of other habitats has yet to be determined, but would appear to be low.

Probably all three alternatives have some element of reality. It seems likely that 1) some patch complexes are isolated from others and have been for long periods of time; 2) some relatively long distance movements may increase gene flow, supplement small populations, and allow for recolonization of extirpated patches; and 3) while bog lemmings use a variety of habitats to a limited (and largely unknown) extent, bog and fen habitats hold the densest populations of lemmings.

### Research Methods.

How do we get the information on distribution, habitat use, and movement that we need to manage this species? Distributional information, and to a lesser extent habitat use, has often been gathered using snap-traps. Detailed habitat use and movement data for small mammals are most commonly obtained using mark-recapture techniques with live traps. However, for northern bog lemmings, live traps are of very limited usefulness. This is because Sherman live-trap use: 1) is labor intensive throughout the trapping period; 2) has very low success with any bait tried; and 3) results in at least some mortality (4 of 6 known captures) (Pearson 1991, Reichel and Beckstrom 1993). Pitfalls, used as live traps: 1) are labor intensive especially during placement; 2) cannot be used in the saturated soil situations commonly encountered in bog lemming habitat; and 3) result in at least some mortality during and between trapping periods. Given these drawbacks, it seems doubtful that live-trapping methods, by themselves, will yield much information on habitat use, population parameters, movements, or home range sizes. Incidental mortalities may be a significant factor over a study of sufficient duration to yield good information. Additionally, live-trapping to locate populations will require at least 10 times the effort and cost compared to snap-trapping, and still cause some mortality. Given the very low Sherman live-trapping success, negative results for even 1000 trap-nights per site would not provide much confidence that lemmings are not present.

Dropping boards may provide one option, but we think differentiating northern bog lemming droppings from other voles will be difficult. Jones and Birney (1988) report that northern bog lemming droppings are bright green while other vole droppings are brown or black. However, we found that at least some bog lemmings had brown droppings. If color alone is used to differentiate the droppings, it may lead to serious biases. Pearson (1991) was not confident of identification of droppings (*Microtus* versus *Synaptomys*) in a test of the technique in Glacier National Park. He did speculate that it could be possible using more sophisticated identification techniques.

Snap-trapping for bog lemmings was much more successful than live-trapping although only 3 females were captured using this method (at all locations in Montana in 1992 and 1993). It appears to be the method of choice for initial survey work to find new populations, both from an economic and time-constraint view. Concerns have been expressed that snap-trapping is not a suitable technique to use on a “sensitive species.” This argument may have some validity from a public perception point of view, but has little or no biological basis (Reichel and Beckstrom 1993).

Very small radio-telemetry packages have recently been used to study other voles and this technique seems to hold the most promise for studying *Synaptomys*. It would require relatively few individuals to be captured, and recapture of those individuals would not be necessary. It would seem to be the method of choice for examining activity patterns, habitat selection and use, home range size, and typical movements by *Synaptomys*.

Long range movements, such as dispersal, are more difficult to determine using radio-telemetry. This is due to 1) the relative rarity of such movements; and 2) time and equipment limitations for finding animals moving far from their expected location. Indirect means of determining the amount of inter-patch movement are available using biochemical analyses of various types to measure gene flow. This may be a viable approach to learning about inter-patch movements and gene flow.

## **STATEWIDE MANAGEMENT RECOMMENDATIONS AND RESEARCH NEEDS**

Based on limited observations at the sites where bog lemmings have been found, several interim management recommendations can be made. We feel that these are the minimum necessary to maintain viable bog lemming populations. Additional research is needed which may lead to other management actions necessary for maintaining viable bog lemming populations.

- 1) Lacking surveys at specific sites, assume northern bog lemmings are present at sphagnum or other fen/bog moss habitat patches in north Idaho and western Montana during land management planning processes.
- 2) Do not harvest timber within 100 m of sphagnum or other fen/bog moss mats or associated riparian areas which could provide corridors for inter-patch movements.
- 3) Minimize domestic livestock grazing in drainages with unsurveyed moss mats present. Range conditions in riparian areas with moss mats should be maintained in good to excellent categories. Stocking rates should be reduced to a point where rapid recovery occurs if either 1) current range condition is fair or poor; or 2) livestock are impacting moss mats.
- 4) No management activities which could destroy moss mats should be undertaken. Examples could include (but are not limited to): 1) road building in, or in some cases upslope from, bogs/fens; 2) pothole blasting in bogs/fens; 3) trail construction across or adjacent to bogs/fens; 4) dam construction upstream from bogs/fens, or downstream if flooding of bogs/fens would occur; and 5) snowmobile use in bogs/fens which could compact vegetation or collapse lemming runways or nests.

Very little information is available on the northern bog lemming. Even the distribution in the U.S. is poorly understood, and most populations have been found within the past 15 years. Habitat use by northern bog lemmings has never been determined in any systematic way. Descriptions of occupied habitat consist of anecdotal accounts of where each specimen was captured; only about 35 individuals had been collected in the Pacific Northwest prior to 1990. Reichel and Beckstrom (1993, 1994) contain detailed vegetative descriptions for six lemming sites in Montana. Food habits and reproductive information in the literature are also limited to a very few anecdotal accounts. Analysis of food from stomachs of bog lemmings captured at six sites in western Montana show mosses composed 29-92% of the diet (by volume) with *Sphagnum* moss averaging <1%. Sedges (1-64%) and grasses (0-8%) composed most of the rest of the diet (Reichel, unpubl. data). No information is available on such topics as movements, population densities, longevity, or home range. Much additional research is required to make intelligent land management decisions where northern bog lemmings are present. We recommend the following as the highest priority needs:

- 1) Conduct additional surveys to better understand macro- and micro- distribution in Montana; on a state-wide basis this should include surveys on the Dillon Resource Area, Headwaters Resource Area, Helena National Forest, Deerlodge National Forest, Gallatin National Forest, Custer National Forest, Lewis and Clark National Forest (Jefferson Division), and sites on the Beaverhead National Forest south and east of Maybee Meadows.
- 2) Analyze all stomachs of bog lemmings collected to provide additional food habits information; this should give some indication of potential habitat use.
- 3) Conduct plant community surveys at all known bog lemming locations. This should include identification of dominant mosses present.
- 4) Gather information on the autecological requirements of the mosses found at bog lemming sites.
- 5) Carry out research on northern bog lemming habitat use. Given the extreme difficulty in capturing the northern bog lemming, radio-telemetry is probably the only viable means to obtain satisfactory answers as to how bog lemmings use habitat within their home ranges.
- 6) Carry out research on northern bog lemming movements to gather information on home ranges and possibly dispersal. This information needs to be integrated with simultaneously collected habitat use data. Again, we feel radio-telemetry is the only viable methodology available.
- 7) Carry out biochemical research on allelic diversity and gene flow between habitat patches. It is possible that hair/skin from specimens already collected could be used for analysis. This should be done utilizing information on patch size and isolation, across the range of the lemming in Montana. Ideally, Montana information should be compared to information from a population in Canada at a site with relatively continuous habitat over a large area.

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## APPENDIX I. NORTHERN BOG LEMMING PVA MODEL DESIGN PARAMETERS

### Life-cycle of the northern bog lemming.

STAGE CLASSES	APPROXIMATE AGES	DURATION OF STAGE
Subadult	90-180 days	3 months
Adult-first litter	180-270 days	3 months
Adult-second litter	>270 days	NA

### Population projection matrix for northern bog lemmings with a pre-birth pulse.

$$\begin{array}{ccc}
 m_1 S_0 & m_2 S_0 & m_3 S_0 \\
 S_1 & 0 & 0 \\
 0 & S_2 & 0 \\
 0 & 0 & S_3
 \end{array}$$

where:

$m_1$  = maternity rate subadults

$m_2$  = maternity rate adults first litter

$m_3$  = maternity rate adults second litter

$S_0$  = survival to subadult

$S_1$  = survival to adult

$S_2$  = survival of adults to breed a second time

$S_3 = 0$

The projection interval is 3 months, the average interbirth interval.

### Calculation of variables in the projection matrix:

$m_1$  = maternity rate subadults = (average litter size of subadults)(proportion of subadult females breeding).

We calculated the maternity rate of subadults as an average of the two projection intervals calculated from museum records:

$$m_1 = [(3.5)(0.57) + (3.25)(0.125)]/2 = 1.201$$

$m_2$  = maternity rate adults first litter = (average litter size of adults first litter)(proportion of females breeding)

Calculated from museum records for females collected:

$$m_2 = (4.28)(0.75) = 3.21$$

$m_3$  = maternity rate adults second litter = (average litter size)(proportion of females breeding)

Calculated from museum records for females collected:

$$m_3 = (3.9)(0.4848) = 1.89072$$

$S_0$  = survival to subadult

From Beasley and Getz (1986) for southern bog lemmings in southern Illinois (see results):

$$S_0 = 0.4100$$

$S_1$  = survival of subadults to adult

From Beasley and Getz (1986) for southern bog lemmings in southern Illinois (see results):

$$S_1 = 0.4100$$

$S_2$  = survival of adults to breed a second time

From Gaines et al. (1997) for southern bog lemmings in Kansas:

average adult 2-week survival rate in summer = 0.7067 (SE = 0.499)

average adult 2-week survival rate in winter = 0.7683 (SE = 0.0601)

Survival over the prediction interval (3 months), is the 2-week survival rate times 6, or  $0.7067^6$  (=0.1245) in summer, and  $0.7683^6$  (=0.2057) in winter. Dispersing adults were taken into account by adding 0.1 to summer and winter adult survival rates, increasing them to 0.2245 and 0.3057, respectively.

Adults may breed a second time in the same summer they had their first litter, or may breed a second time after overwinter survival. Survival rate of adults to breed a second time was calculated as summer and winter survival rates weighted by maternity rates of first and second litters, respectively:

$$\begin{aligned} S_2 &= (0.75)(0.2245) + (0.4848)(0.3057) \\ &= 0.1684 + 0.1482 \\ &= 0.3166 \end{aligned}$$

$$S_3 = 0$$

These variables were inserted in the Leslie matrix as follows:

$(1.201)(0.4100)$	$(3.21)(0.4100)$	$(1.8907)(0.4100)$
0.4100	0	0
0	0.3166	0

The Leslie matrix calculated from the variables is:

0.4924	1.3161	0.7752
0.4100	0	0
0	0.3166	0

### Demographic and environmental stochasticity

Demographic and environmental stochasticity was modeled from the standard errors of the estimates for survival, litter size, and proportion of females breeding used in the population matrix. The stochasticity matrix takes the same form as the Leslie matrix for population projection, except in this case the variables represent the standard errors of the estimates rather than the average value for the variable:

$([se]m_1 [se]S_0)$	$([se]m_2 [se]S_0)$	$([se]m_3 [se]S_0)$
$(se)S_1$	0	0
0	$(se)S_2$	0
0	0	$(se)S_3$

Standard errors for survival were calculated from replicate samples (years and/or populations) reported in the literature. Litter size standard errors were from replicate females used to estimate the mean litter size, as presented in the Results section.

These variables were inserted in the Leslie matrix as follows:

$(0.6915)(0.2399)$	$(1.63)(0.2399)$	$(1.1)(0.2399)$
0.2399	0	0
0	0.0419	0

The Leslie matrix for stochasticity is thus:

0.1659	0.3910	0.2639
0.2399	0	0
0	0.0419	0

Sources used to develop the model include:

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## APPENDIX II. MUSEUMS CONTACTED AND RESULTS

Provincial Museum of Alberta, Edmonton: received data on 15 specimens  
University of Alberta Museum: received data on 27 specimens  
British Columbia Provincial Museum: received data on 77 specimens  
University of British Columbia: received data on 73 specimens  
Manitoba Museum of Man and Nature, Winnipeg: received data on 78 specimens  
University of Manitoba: no reply  
New Brunswick Museum, Saint John: received data on 1 specimen  
Carleton Univ. Mus. (Ontario): no reply  
Canadian Museum of Man and Nature, Ottawa: received data on 216 specimens  
Royal Ontario Museum, Toronto: received data on 147 specimens  
Redpath Museum, McGill University, QB: : have no *S. borealis*  
Saskatchewan Museum of Natural History: no reply  
University of Saskatchewan, Saskatoon: received data on 15 specimen  
AK Dept Fish and Game: called to say now specimens were primarily at Univ. AK, with some at TX  
A&M and Univ. Ill.  
University of Alaska Museum: received data on 74 specimens  
University of Arizona: : no reply  
California Academy of Sciences, San Francisco: have no *S. borealis*  
California State University, Fresno: : no reply  
Natural History Museum of Los Angeles County: have no *S. borealis* (phone 5/18/94)  
Museum of Vertebrate Zoology, University of California, Berkeley: received data on 39 specimens  
University of California, Los Angeles: received data on 10 specimens  
University of Colorado, Boulder: received data on 2 specimens  
University of Connecticut, Storrs: have no *S. borealis*  
National Museum of Natural History, Washington, DC: received data on 165 specimens  
Florida Museum of Natural History, University of Florida, Gainesville: have no *S. borealis*  
Field Museum of Natural History, Chicago, IL: received data on 51 specimens  
University of Illinois, Urbana: received data on 6 specimens  
Fort Hays State University, Museum of the High Plains, KS: : no reply  
University of Kansas, Lawrence: received data on 18 specimens  
Harvard University, Museum of Comparative Zoology, Cambridge: received data on 34 specimens  
Mich. State University, East Lansing: received data on 2 specimens  
University of Michigan, Ann Arbor: received data on 4 specimens  
University of New Mexico, Museum of Southwestern Biology: received data on 1 specimen  
American Museum Natural History, New York, NY: received data on 71 specimens  
University of Oklahoma: received data on 39 specimens  
Carnegie Museum of Natural History, Penn.: no reply  
Philadelphia Academy of Natural Sciences: have no *S. borealis*  
Texas A&M: no reply  
Texas Tech University, Lubbock: have no *S. borealis*